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(54) **Star coupler.**

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Description

Field of the Invention

This invention relates generally to optical coupling and particularly to an optical coupler that divides the optical energy of any one of M inputs among N outputs.

Background of the Invention

In optical systems which involve the transmission of guided light between two locations, there is often a need for dividing light that has been transmitted along one or more channel waveguides among several channel waveguides for further transmission.

This invention specifically relates to an M X N optical waveguide coupler as specified in the preamble of claim 1 and claim 2 respectively.

In DE-U-78 08 787 a 1 x 5 coupler is depicted, having a pair of opposed edges at least one of said edges being shaped essentially as an arc of a circle whose centre is located essentially at the centre of said other opposed edge, a waveguide on one opposed edge, and an array of 5 waveguides spaced essentially uniformly along said other opposed edge. The input and output waveguides are optical fibres embedded in slots in the planar waveguide.

EP-A-0 048 408 describes an M X N planar optic coupler comprising a planar waveguide having a pair of opposed parallel edges, a first set of M input waveguides (3 at left of figure 1a) perpendicular to one of said parallel edges for introducing optical signals to said planar waveguide for transmission therealong, where M is at least one, and a second set of N output waveguides (3 at right of figure 1a) perpendicular to said other parallel edge for receiving at least portions of optical signals transmitted by said planar waveguide where N is greater than 1.

Typically, M X N prior art couplers have been complex and not easily manufactured or else have been inefficient and have provided undesirably wide variations in the degree of coupling between different ports.

The present invention, therefore, seeks to provide a coupler with M X N ports that is easy and relatively inexpensive to fabricate wherein the uniformity of the coupling is increased. The above technical problem is solved by the characterizing features of claims 1 and 2 respectively.

This means that in-order to increase the uniformity of the coupling, the width of the channel of an individual waveguide is adjusted to compensate for its distance from the central point of the joining edge.

Similarly, fan-out may be used to increase the separation of individual waveguides where they are to be coupled to other waveguides.

Brief Description of the drawings

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 shows, schematically, an M X N coupler in accordance with one embodiment of the invention; and

FIG. 2 shows, schematically, an M X N coupler in accordance with another embodiment of the invention.

Detailed Description

In FIG. 1, there is shown an M X N star coupler in accordance with the present invention in which each of the M identical channel waveguides 31 is coupled to each of the N identical channel waveguides 32 by way of the intermediate planar waveguide 30. The edge 30A along which each of the channel waveguides 31 is joined to the planar waveguide corresponds essentially to the arc of a circle whose center B is near the center of the opposite edge 30B of the planar waveguide 30 and the axis of each channel waveguide 31 is essentially radially aligned with point B. Edge 30B is similarly shaped with respect to a point A at the center of edge 30A, and the axis of each of the channel waveguides 32 is essentially radially aligned with point A. The two arrays may be described as confocally disposed with respect to the planar waveguide 30. Typically, points A and B may be spaced between about 0.1 millimeters and 1.0 centimeters apart depending on the number of ports being intercoupled.

The spacing between channel waveguides advantageously is as close as possible without introducing evanescent coupling between adjacent waveguides.

In this coupler, the portions of the edge 30A which serve as the input planes of the plane waveguide 30 are all angled to be perpendicular to their associated channel waveguide so that the wave exits without bending. Moreover, it is usually desirable that each of channel waveguides 31 and 32 be single mode guides.

As such, the width of each of the guides is determined by the wavelength of the optical wave being transmitted and the index of refraction of the channel. Typically, for operation at about 0.8 microns wavelength with silver-doped channels formed in soda-lime glass substrates by ion-exchange, the width of each channel guide is about 1

to 2 microns wide, and their separation at the edges 30A and 30B may be several microns, so that arrays of 64 input and 64 output ports can readily be accommodated.

The depths of the channel waveguides and the planar waveguide are essentially the same and typically somewhat less than a micron. This depth is determined by the length of time the glass substrate is exposed to the ion-exchange treatment in the formation of the waveguides.

The channel waveguides generally are patterned by photolithographic techniques involving masks. In some instances it may prove desirable to simplify the preparation of the masks used for defining the channel by using a parallel array of channel waveguides to couple to the planar waveguide rather than radially aligned channel waveguides.

In FIG. 2, there is shown a coupler 40 in accordance with the present invention that employs a parallel array of M channel waveguides 41 which are joined to the planar waveguide 42 along edge 42A. In this instance, the portions of the edge 42A which serve as the input planes of the various channel waveguides 41 are appropriately angled so that they largely lie along an arc of a circle whose center is at C. Accordingly, each of the beams exiting from the individual channel waveguides 41 is refracted to the focal point C at the opposite edge 42B of the planar waveguide 42. This design makes it convenient to arrange each of the channel waveguides to be parallel to one another, as shown, and to make all of the input plane portions straight. These factors simplify the preparation of the mask used to define this geometry.

In this coupler, additionally, the array of N output channels waveguides 43 are shown joined to the opposite edge 42B of the planar guide 42, that is straight, rather than curved, at some sacrifice in uniformity of coupling. Advantageously, the waveguides 43 are centered about point C. It is, of course, feasible to utilize an output array of channel waveguides in the manner of input array so that the wave energy received in each output channel wave guide is also refracted to be launched appropriately along the output channel guide with minimum coupling loss. However, the use of the arrangement shown further simplifies the preparation of the mask. Accordingly, when this becomes an important consideration, the arrangement of output couplers depicted in FIG. 2 may sometimes be preferred.

As previously indicated, it is usually desirable to pack the individual channels of both the input and output arrays of channel fibers as closely as possible where each joins the planar waveguide to improve the filling factor for maximum efficiency as well as for increased compactness. Typically, this may involve spacing of only several microns, for example, between 3 and 6 microns, between channel waveguides where they join the planar waveguide. However, this spacing is too close if each channel waveguide is to couple along a common plane separately to an optical fiber that typically will have a diameter larger than this spacing.

To solve this problem, the various output channel waveguides may be spread apart as widely as desired by the fan-out pattern shown in FIG. 2 in which each channel waveguide 43 is appropriately redirected as shown so that at the coupling plane 45 that extends normal to the output edge 42B, the various channel waveguides may be widely separated for easy coupling to the fibers 46. Of course, necessary precautions should be taken to insure that the bend is gradual enough to avoid large bending losses.

There may similarly be fanned-out the input ends of the input array of channel waveguides 41, if this is desired.

As previously indicated, the parallel arrangement depicted in FIG. 2 for the output array of channel waveguides tends to non-uniformity in coupling in the absence of special measures, if the output array of channel waveguides 43 are identical. In particular, the further an individual output channel wave 43 is from the central point C, the less energy it will typically capture since the concentration of wave energy along the edge 42B falls off with increasing distance from C. To compensate, the widths of the individual channels of waveguides 43 may be tailored so that the further a waveguide is from the central point C, the wider the width of its channel at edge 42B where it joins the planar waveguide 42, and the correspondingly larger amount of wave energy captured. If maintaining each channel waveguide to be single mode is critical, care needs to be taken to avoid making the waveguide multi-mode as the channel is widened. By decreasing the amount of dopant in the channel to reduce its index of refraction as the width of the channel is widened, the modal properties of the waveguide may be essentially maintained. This selective widening technique can similarly be used, if desired, to improve the uniformity of coupling between the output guides of the coupler shown in FIG. 1.

It, should be appreciated that couplers are sometimes needed to be reciprocal in which the roles of the input and output guides are reversed so that the various factors mentioned in connection with the waveguides described as the input wave guides would be applicable to the waveguides described as the output waveguides and vice versa.

It should be apparent that known photolithographic techniques in combination with known ion-exchange processes can readily be used to form

the described structures. Various other techniques similarly are available for preparation of the couplers described.

Claims

1. An M X N optical waveguide coupler comprising a planar waveguide (42) having a pair of opposed edges (42A, 42B) at least one (42A) of said opposed edges being shaped essentially as an arc of a circle whose center (C) is located essentially at the center of said other opposed edge (42B), an array of M channel waveguides (41) spaced essentially uniformly along said at least one opposed edge (42A), and an array of N channel wave guides (43) spaced essentially uniformly along said other opposed edge (42B) wherein said channel waveguides (41; 43) are formed in the substrate in which the planar waveguide (42) is formed and at least one of M and N is greater than 1, wherein each of the M channel waveguides (41) joins the planar waveguide (42) with the exit faces (42A) of such channel waveguides (41) shaped to refract their exiting beams towards said center (C) of the opposite edge (42B) of the planar waveguide (42), characterized in that the width of each channel of the N channel waveguides (43) increases with its distance from said center (C).

2. An M X N optical waveguide coupler comprising a planar waveguide (30) having a pair of opposed edges (30A) at least one (30A) of said opposed edges being shaped essentially as an arc of a circle whose center (B) is located essentially at the center of said other opposed edge (30B) an array of M channel waveguides (31) spaced essentially uniformly along said at least one opposed edge (30A) and an array of N channel wave guides (32) spaced essentially uniformly along said other opposed edge (30B) wherein said channel waveguides (31; 32) are formed in the substrate in which the planar waveguide (30) is formed and at least one of M and N is greater than 1, wherein each of the M channel waveguides (31) is joined to the planar waveguide (30) in a manner to have the axis of its channel aligned with said center (B), characterized in that the width of each channel of the N channel waveguides (32) increases with its distance from said center (B).

3. The M X N coupler of claim 2 in which said other opposed edge (30B) is shaped essentially as the arc of a circle whose center (A) is located essentially at the center of said at least one opposed edge (30A).

4. The M X N coupler of claim 3 in which each of the M and N channel waveguides (37, 32) is joined to its edge of the planar waveguide (30) in a manner that the axis of its channel is aligned with the center (B; A) of the opposed edge.

5. The M X N coupler of claim 1 in which the N channel waveguides (43) join the planar waveguide (42) along a straight edge. (42B)

6. The M X N coupler of claim 1 or 2 in which at least some of the waveguides of at least one of the array of channel waveguides are fanned-out to increase the spacing between said some waveguides at a coupling plane (45) where each of the waveguides is to be coupled to an optical fiber (46).

Patentansprüche

1. Optischer M x N Wellenleiterkoppler mit einem planaren Wellenleiter (42), der zwei gegenüberliegende Ränder (42A, 42B) besitzt, von denen wenigstens ein Rand (42A) der gegenüberliegenden Ränder im wesentlichen als Kreisbogen gestaltet ist, dessen Mittelpunkt (C) im wesentlichen in der Mitte des anderen gegenüberliegenden Randes (42B) liegt, mit einer Gruppe von M Wellenleiterkanälen (41), die im wesentlichen gleichförmig längs wenigstens des einen (42A) der gegenüberliegenden Ränder angeordnet sind, und mit einer Gruppe von N Wellenleiterkanälen (43), die im wesentlichen gleichförmig längs des anderen gegenüberliegenden Randes (42B) angeordnet sind, wobei die Wellenleiterkanäle (41; 43) in dem Substrat ausgebildet sind, in dem der planare Wellenleiter (42) ausgebildet ist, und wobei M und/oder N größer als 1 ist und wobei jeder der M Wellenleiterkanäle (41) mit dem planaren Wellenleiter (42) so verbunden ist, daß die Austrittsflächen (42A) eines jeden Wellenleiterkanals (41) so gestaltet sind, daß die austretenden Strahlen nach der Mitte (C) des gegenüberliegenden Randes (42B) des planaren Wellenleiters (42) gebrochen werden, dadurch gekennzeichnet, daß die Breite eines jeden Kanals der N Wellenleiterkanäle (43) mit seinem Abstand vom Mittelpunkt (C) zunimmt.

2. Optischer M x N Wellenleiterkoppler mit einem ebenen Wellenleiter (30), der zwei gegenüberliegende Ränder (30A, 30B) aufweist, wobei wenigstens einer (30A) der gegenüberliegenden Ränder im wesentlichen als Kreisbogen

gestaltet ist, dessen Mittelpunkt (B) im wesentlichen in der Mitte des anderen gegenüberliegenden Randes (30B) der Gruppe von M Wellenleiterkanälen (31) liegt, die im wesentlichen gleichförmig längs des wenigstens einen gegenüberliegenden Randes (30A) angeordnet sind, und mit einer Gruppe von N Wellenleiterkanälen (32), die im wesentlichen gleichförmig längs des anderen gegenüberliegenden Randes (30B) angeordnet sind, wobei die Wellenleiterkanäle (31; 32) in dem Substrat ausgebildet sind, in dem der ebene Wellenleiter (30) ausgebildet ist, und M und/oder N größer als 1 ist, und wobei jeder der M Wellenleiterkanäle (31) mit dem planaren Wellenleiter (30) derart verbunden ist, daß die Achse des betreffenden Kanals auf den Mittelpunkt (B) ausgerichtet ist, dadurch gekennzeichnet, daß die Breite eines jeden Kanals der N Wellenleiterkanäle (32) mit dem Abstand vom Mittelpunkt (B) ansteigt.

3. M x N Koppler nach Anspruch 2, bei welchem der andere gegenüberliegende Rand (30B) im wesentlichen als Kreisbogen ausgebildet ist, dessen Mittelpunkt (A) im wesentlichen in der Mitte des wenigstens einen gegenüberliegenden Randes (30A) liegt.

4. M x N Koppler nach Anspruch 3, bei welchem jeder der M und N Wellenleiterkanäle (31, 32) mit dem Rand des ebenen Wellenleiters (30) in der Weise verbunden ist, daß die Kanalachse auf den Mittelpunkt (B; A) des gegenüberliegenden Randes ausgerichtet ist.

5. M x N Koppler nach Anspruch 1, bei welchem die N Wellenleiterkanäle (43) mit dem ebenen Wellenleiter (42) längs eines geraden Randes (42B) verbunden sind.

6. M x N Koppler nach Anspruch 1 oder 2, bei welchem wenigstens einige der Wellenleiter wenigstens einer Gruppe von Wellenleiterkanälen ausgefächert sind, um den Abstand zwischen einigen Wellenleitern in einer Koppelebene (45) zu vergrößern, wo jeder der Wellenleiter mit einer optischen Faser (46) gekoppelt werden muß.

Revendications

1. Coupleur M X N pour guide d'onde optique, comprenant un guide d'onde plan (42) avec une paire de bords opposés (42A, 42B), l'un au moins (42A) desdits bords opposés ayant sensiblement la forme d'un arc de cercle dont le centre (C) est situé sensiblement au centre dudit autre bord opposé (42B), une rangée de M guides d'onde (41) à canal répartis de façon sensiblement uniforme le long dudit au moins un bord opposé (42A), et une rangée de N guides d'onde (43) à canal répartis de façon sensiblement uniforme le long dudit autre bord opposé (42B), dans lequel lesdits guides d'onde à canal (41, 43) sont formés dans le substrat dans lequel est formé le guide d'onde plan (42), l'un au moins de M et de N est supérieur à 1, chacun des M guides d'onde à canal (41) est réuni au guide d'onde plan (42), les faces de sortie (42A) de ces guides d'onde à canal (41) ayant une forme qui va réfracter leur faisceau de sortie en direction du centre (C) du bord opposé (42B) du guide d'onde plan (42), caractérisé en ce que la largeur de chaque canal des N guides d'onde à canal (43) augmente en même temps que son éloignement dudit centre (C).

2. Coupleur M X N pour guide d'onde optique, comprenant un guide d'onde plan (30) avec une paire de bords opposés (30A, 30B), l'un au moins (30A) desdits bords opposés ayant sensiblement la forme d'un arc de cercle dont le centre (B) est situé sensiblement au centre dudit autre bord opposé (30B), une rangée de M guides d'onde (31) à canal répartis de façon sensiblement uniforme le long dudit au moins un bord opposé (30A), et une rangée de N guides d'onde (32) à canal répartis de façon sensiblement uniforme le long dudit autre bord opposé (30B), dans lequel lesdits guides d'onde à canal (31, 32) sont formés dans le substrat dans lequel est formé le guide d'onde plan (30) et l'un au moins de M et de N est supérieur à 1, dans lequel chacun des M guides d'onde à canal (31) est réuni au guide d'onde plan (30) de manière à ce que l'axe de son canal soit aligné avec ledit centre (B), caractérisé en ce que la largeur de chaque canal des N guides d'onde à canal (32) augmente en même temps que son éloignement dudit centre (B).

3. Coupleur M X N selon la revendication 2, dans lequel ledit autre bord opposé (30B) a sensiblement la forme d'un arc de cercle dont le centre (A) est situé sensiblement au centre dudit au moins un bord opposé (30A).

4. Coupleur M X N selon la revendication 3, dans lequel chacun des M et N guides d'onde à canal (31, 32) est réuni au bord du guide d'onde plan (30) de manière à ce que l'axe de son canal soit aligné avec le centre (B, A) du bord opposé.

5. Coupleur M X N selon la revendication 1, dans lequel les N guides d'onde à canal (43) rejoignent le guide d'onde plan (42) le long d'un bord rectiligne (42B).

6. Coupleur M X N selon la revendication 1 ou 2, dans lequel certains au moins des guides d'onde d'au moins l'une des rangées de guide d'onde à canal sont disposés en forme d'éventail pour augmenter l'espacement entre lesdits certains guides d'onde au niveau d'un plan de couplage (45) où chacun des guides d'onde doit être couplé à une fibre optique (46).

FIG. 1

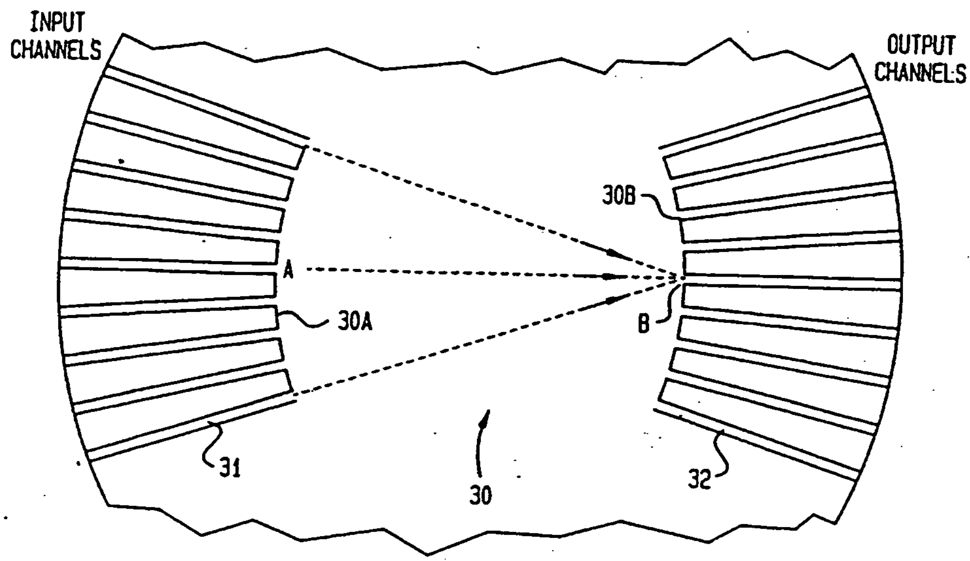
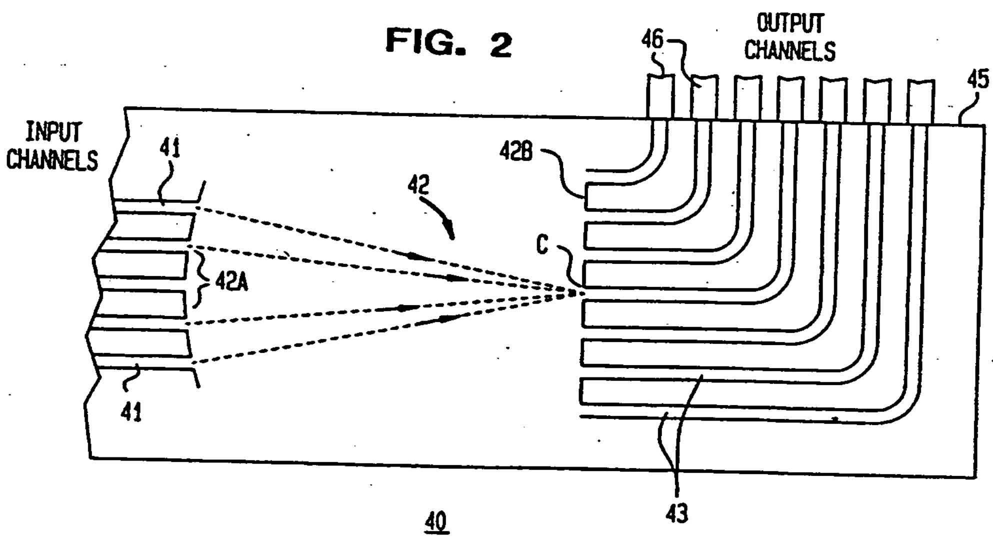

INPUT CHANNELS
OUTPUT CHANNELS
30B
A
30A
B
31
30
32

FIG. 2


46
OUTPUT CHANNELS
45
INPUT CHANNELS
41
42B
42
C
42A
41
43
40